PERSPECTIVES ON VEHICLE CRASH COMPATIBILITY AND RELATIONSHIP TO OTHER SAFETY CRITERIA

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Paper Number 412

ABSTRACT

A study of accident data for vehicle-to-vehicle collisions shows that for injuries of AIS equal to or greater than 3, significant portions of vehicles' front structures are involved in the crash, both in frontal and in side impacts. Analysis presented here also shows that most of the LTV-to-car crashes are side impacts and that these side impacts account for 57 percent of the total harm associated with LTV-to-car crashes. These frontal and side impacts between LTVs and cars are further divided by the location and the direction of impact.

It has been shown earlier that the use of fixed barriers as test devices for crashworthiness is likely to lead to front structures of larger vehicles being designed for higher force levels than the front structures of smaller vehicles, the overall effect being decreased crash compatibility between vehicles. The effect of the side impact barrier, used for compliance with dynamic FMVSS 214, as shown by updated data, is again observed to be improved compatibility between vehicles of different sizes.

INTRODUCTION

The issue of crash compatibility between a large vehicle and a small vehicle has generally been investigated in terms of the ability to protect the occupant of the smaller vehicle. The terms 'self protection' and 'partner protection' have been used - 'self protection' usually refers to the protection of the occupants in the larger vehicle and 'partner protection' to the protection of the occupants in the smaller vehicle. In this context, the 'larger vehicle' is generally a light-truck based vehicle (LTV) such as a pick-up or a sport utility vehicle in the USA whereas it may refer to a large car in Europe and in Japan.

There have been several studies published over the years examining various aspects of this issue and most of these can be broadly classified into two categories. The first category is that of studies of the vehicle parameters (such as height, stiffness, etc) of the larger vehicle that affect 'partner protection' and rank them in order their relative significance. The second category of these studies consists of investigations[1-3] of test configurations and test barriers that might be considered for quantitative assessment of 'partner protection' by the larger vehicles. These may be of particular interest to the various agencies regulating vehicle safety since, if such a test configuration can be identified, it can be used as a basis of regulations requiring certain performance levels for vehicles.

In one study, Summers et al[4] analyzed 1995-1999 data from the Fatal Accident Reporting System (FARS) and the General Estimate System (GES) and proposed an 'aggressivity metric' for vehicles involved in vehicle-to-vehicle crashes. The authors used broad commercial categories of US vehicle fleet to estimate the numbers for their 'metric' and no relationships were studied between the specific design characteristic of a vehicle and its accident affecting the 'partner protection'. Some of the other studies on vehicle factors affecting crash compatibility have attempted to identify the portion of the larger vehicle's front end that is of significance in crashes. Digges et al[5] concluded that the 'vehicle stiffness and geometric measurements during the initial 125 mm of frontal crush are essential for evaluating front-to-side compatibility". In a status report, O'Reilly[6] stated that, among the 'key elements affecting aggressivity in side impacts' is "stiffness distribution of bullet vehicle - Only frontal stiffness (distribution) of bullet vehicle in say first 100 mm is relevant".

In this paper, we analyze accident data from the USA in order to assess the subcategories that LTV-to-car collisions can be divided into in order of significance. We also examine the data for involvement of the vehicle structure in vehicle compatibility.

ANALYSIS OF ACCIDENT DATA

Shown in Figures 1,2 & 3 are analyses of FARS data for the year 2001 for occupants of passenger cars (Figure 1), sport utilities (Figure 2) and other light trucks and vans excluding utility vehicles (Figure 3). For passenger car occupants, fatalities in multiple-vehicle crashes are a larger part of the total fatalities

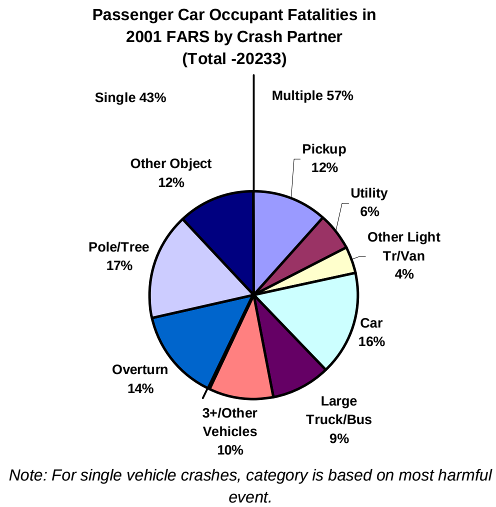

Figure 1: Passenger Car Occupant Fatalities.

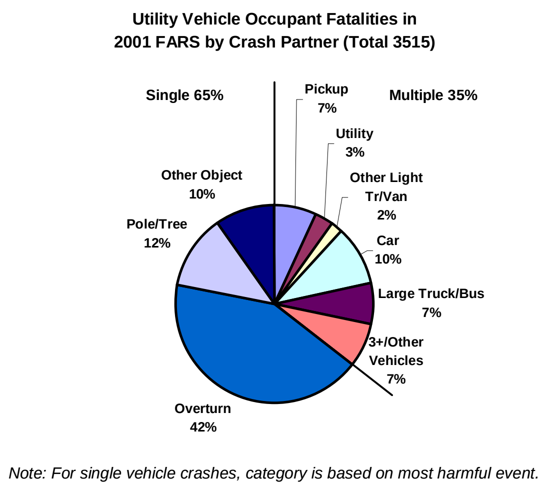

Figure 2: Utility Vehicle Occupant Fatalities.

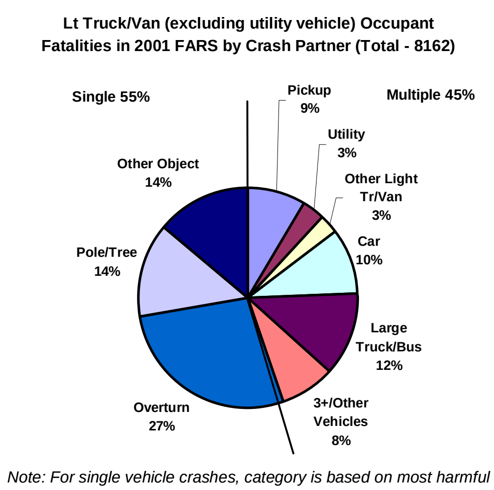

Figure 3: Fatalities in Light trucks & Vans.

than is the case for the occupants of light trucks and vans. However, in all these cases, fatalities in multiple vehicle crashes are significant. The percentages shown in the above figures are related to the total fatalities in that particular segment - 20233 fatalities among passenger car occupants, 3515 fatalities among sport utility vehicle occupants and 8162 fatalities among occupants of other light trucks and vans.

Crash of Front of LTVs into Passenger Car

Accident data from the NASS-CDS for the years 1997-2001 was analyzed to assess the trends in LTV to car crashes. For the present study, only those crashes were included where the crash was identified as the front of the LTV impacting a passenger car. Shown in Figure 4 is the frequency distribution by the impact modes of these crashes. It is observed that the impact of the LTV into the side of a passenger car is the most frequent mode, followed by the impact into the rear and the front of the passenger cars.

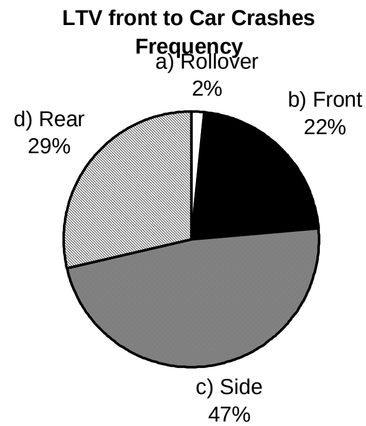

Figure 4: Front of LTV-to-car crashes – direction of impact on car.

Further analysis of all the side impacts is shown in Figure 5, the designations used for identifying the impact direction and location derive from the CDC nomenclature - 'SidePC-FrntAng' are left- or right-side impacts into the side of the passenger compartment with the direction of force between 10 o'clock and 2 o'clock positions; 'SidePC-Perpend' denotes impacts to the passenger compartment with 3 or 9 o'clock directions of force; and 'SideFender' is the group of impacts on the fender of the passenger car from any direction. These three subcategories include almost all of the side impacts occurring between LTVs and cars.

The frequency of front-to-front impacts is similarly divided into subcategories and these impacts are seen to be distributed more evenly among several subcategories; the most significant being left front offset impact at 12 o'clock (FrtOff12-L), left front offset impact at angles other than 12 o'clock (FrtOffOt-L) and front impact at 12 o'clock with distributed damage (FrtDistr).

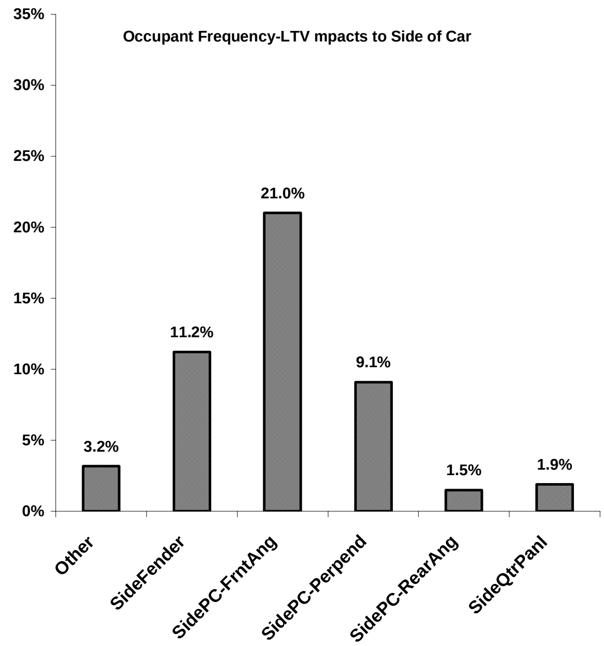

Figure 5: Distribution of Side Impacts of LTVs into cars.

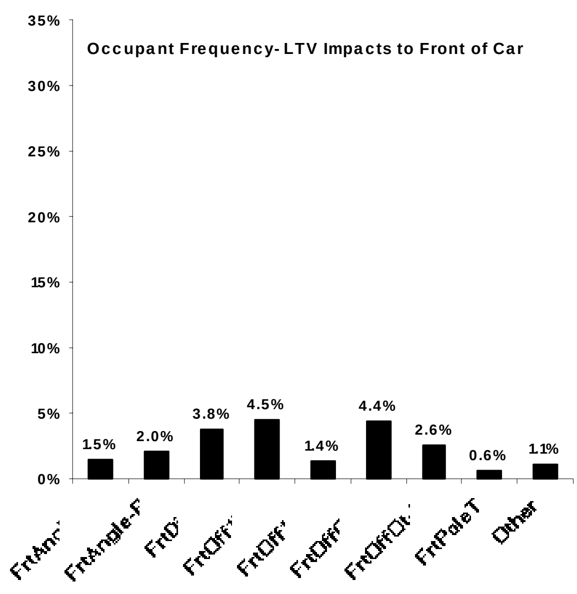

Figure 6: Distribution of Front Impacts of LTVs into cars.

The distribution of occupant injuries of maximum AIS $\geq$ 3 is shown in Figure 7 and it is observed that impacts of LTVs into side of passenger cars account for half of all these cases.

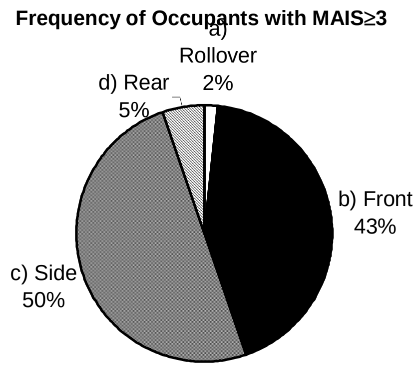

Figure 7: Distribution of injuries of MAIS≥3.

An analysis of the data for occupant harm from the same source is shown in Figure 8 and leads to similar conclusion - the impact of LTVs into sides of passenger cars is the predominant mode of harm in LTV-to-car crashes.

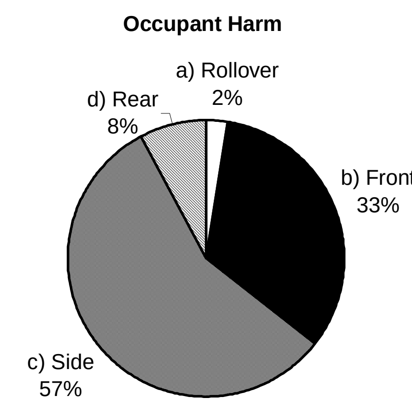

Figure 8: Distribution of harm in LTV to Car crashes.

Further analysis of the 1997-2001 NASS-CDS was conducted to relate the total harm to the location and the direction of impact, as shown in Figure 9 for side impacts and in Figure 10 for frontal impacts. For side impact, almost all of the reported harm is associated with impacts on the passenger compartment, either left- or right-side impacts between10 o'clock and 2 o'clock directions (SidePC-FrntAng) and perpendicular impacts to the passenger compartment (SidePC-Perpend). The first category accounts for a larger proportion of the total harm in side impacts although lateral impacts (3 o'clock and 9 o'clock directions of force) are also a significant proportion.

When compared to the distribution of all side impacts (Figure 5), it is seen that LTV impacts to areas other than the passenger compartment cause little occupant harm.

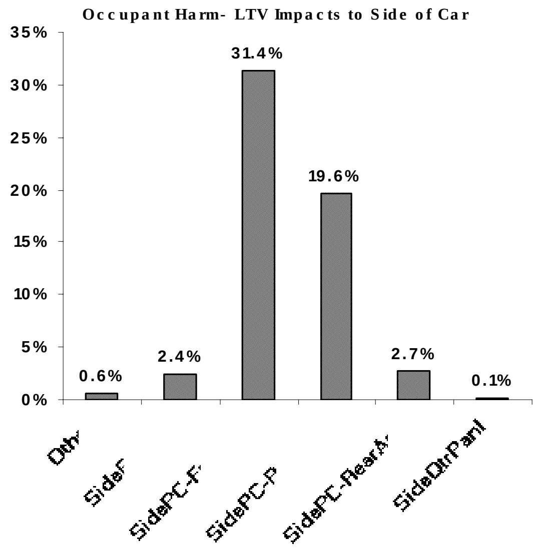

Figure 9: Distribution of harm in side impacts by location & direction.

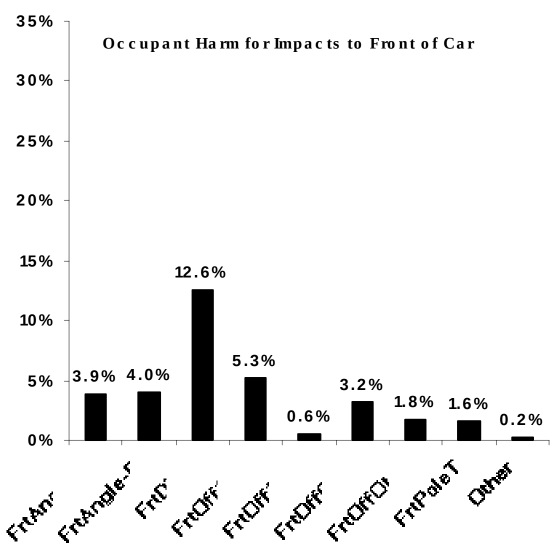

Figure 10: Distribution of harm in front impacts by location & direction.

For frontal impacts, the occupant harm is distributed among several categories of location and direction of impact. In this case, the largest single component is associated with straight (12 o'clock) impacts with distributed damage (FrtDistr) which account for approximately 38% of the total front impact harm.

The front offset impacts on the driver side (FrtOff12-L) form the next largest category with about 16% of the total front impact harm, followed by left- and right-angle impacts to the front of the vehicle (FrtAngle-L and FrtAngle-R). These two angle impacts account for about 24% of the occupant harm in this case.

LTV Crush in Impacts With Passenger Cars

The data in the 1997-2000 NASS-CDS database were also evaluated for the amount of residual crush observed in LTVs when involved in impacts to passenger cars, both to the front and to the side of cars. Figure 11 shows the observed data for the maximum residual crush and Figure 12 for the average residual crush, the data being plotted as separate curves for each level of maximum AIS value (of the occupant on the struck side of the car). The maximum observed crush of the LTVs' front is found to exceed 20 cms for more that 80% of all the reported cases with AIS $\geq$3. Similarly, the average residual crush of the LTVs' front is found to exceed 20 cms or more in more than half of all cases with AIS$\geq$3.

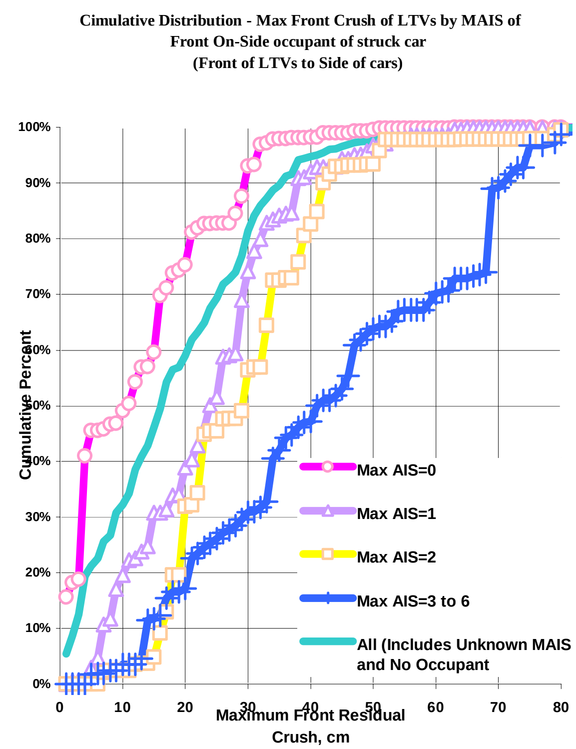

Figure 11: Maximum Residual Crush of LTVs in front of LTV-to-side of passenger car impacts

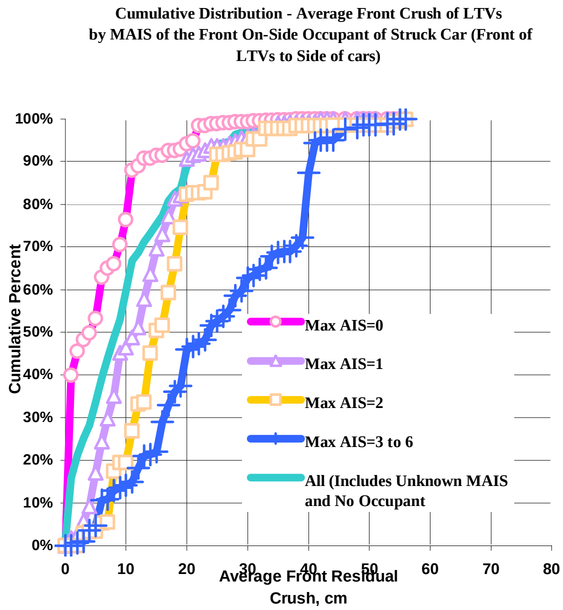

Figure 12: Average Residual Crush of LTVs in Front of LTVs-to-side of passenger cars impacts

Shown in Figure 13 are the plots of cumulative distribution of average residual crush of LTVs in front impacts to cars. Again, separate curves are plotted for various levels of maximum AIS of the front outboard occupant of the car. For maximum AIS $\geq$3, the average residual crush of the LTV exceeds 20 cms in more than 90% of the reported crashes.

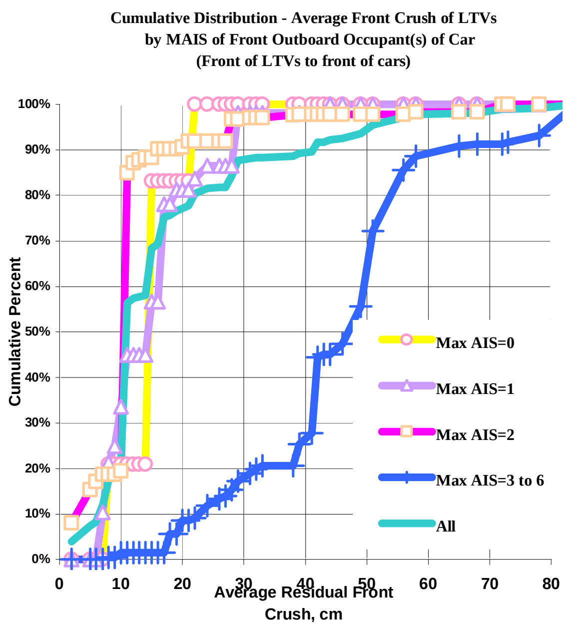

Figure 13: Average Residual Crush of LTVs in front-to-front impacts with cars.

This conclusion that the average residual crush of LTVs is larger when the impact is to the front of the car (than when it is to side) can be explained by the fact that generally more of the structure of the passenger car is engaged in front-to-front impacts. Also, passenger cars (as well as LTVs) have higher structural strength in the front than they do in the side due to the presence of rigid powertrain components in the front load path. But in both cases (front-to-front and front-to-side impacts), the reported data for LTVs and for cars show the involvement of a significant portion of the front structure of the LTV. The amount and the pattern of the vehicle crush will of course depend on many factors such as the speed and the direction of impact, the geometrical and the structural characteristics of the vehicles, etc. But it is important to note the contribution of the total front structure of LTVs in investigating the issues of collision compatibility.

EFFECT OF OTHER SAFETY CRITERIA

There are several safety criteria, regulatory and non-regulatory (consumer metrics tests) that, in combination with other functional requirements of an automobile, determine the design of vehicles. Among the most important criteria governing the structural design of the vehicles' front end are the US Federal Motor Vehicle Safety Standards 208, the frontal New Car Assessment Program (NCAP) and the offset deformable barrier tests conducted by the Insurance Institute of Highway Safety. In a recent publication[7], we have reviewed the effect that these frontal impact requirements have had on the front-end force characteristics of automobiles. The general effect has been towards requiring stronger front ends for heavier vehicles (the force generated by the front end of a vehicle is proportional to its mass, given a fixed crush space). The relationship of the improved frontal NCAP score to improved performance of vehicles in crashes was also examined[7] from available accident data for various vehicle segments and no correlation was observed between the overall rate of fatalities and the frontal NCAP score of a specific vehicle or any vehicle segments. Figure 14 is one of the results from that paper[7] for midsize utility vehicles using FARS database. Data for several other vehicle segments were also presented in that paper. The same conclusion (of no observable relationship to NCAP rating) is reached if the rate of major injuries is included (from database of the above-mentioned states) and the data is normalized to "standardized rate of injuries per 100 occupants'.

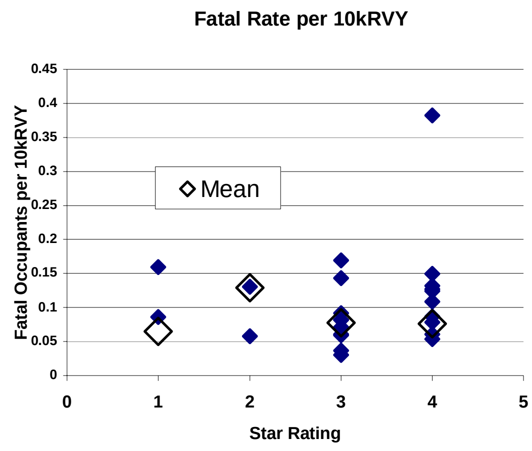

Figure 14: Fatality Rate for Belted Drivers; frontal crashes, midsize utilities (from Ref 7).

The principal criteria governing the side structure of vehicles are the US Federal Motor Vehicle Safety Standard 214 (dynamic) and the lateral New Car Assessment Program. The relationship of these criteria to vehicle compatibility was studied by VanderLugt et al[8] with the conclusion that vehicles designed to meet dynamic FMVSS 214 show lower rates of major injuries and fatalities when impacted by other vehicles. Figure 15 shows updated data obtained from 1994-99 accident files from five states in the USA (Alabama, Florida, Idaho, Maryland, North Carolina) and normalized as percent of all occupants (the stars indicate statistical significance). These represent cases of fatal or major injuries (classified as “K” or “A” in the states’ files) and confirm the earlier findings of improved compatibility for vehicles designed to comply with the dynamic side impact requirement using a moving deformable barrier. A similar conclusion is reached when the FARS data is examined for the years 1994-1999 as shown in Figure 16. It is observed that passenger cars engineered for the dynamic FMVSS 214 show lower rates (per million registered vehicle years) of fatality when impacted by other cars and light trucks.

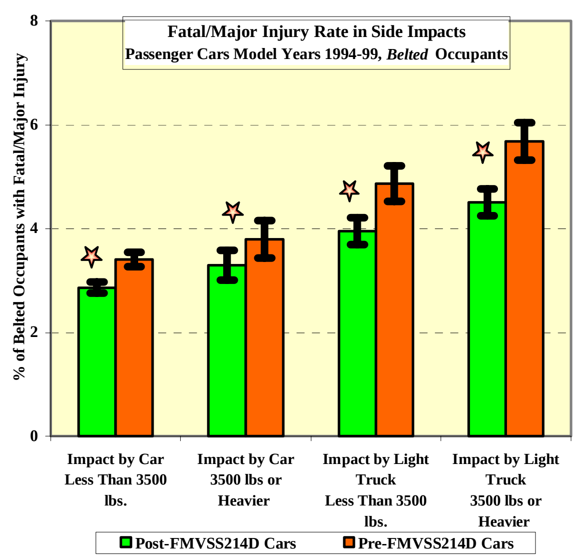

Figure 15: Percentage of belted occupants with fatal/major injuries; Pre-FMVSS214D vs Post-FMVSS214D passenger cars (standardized rates).

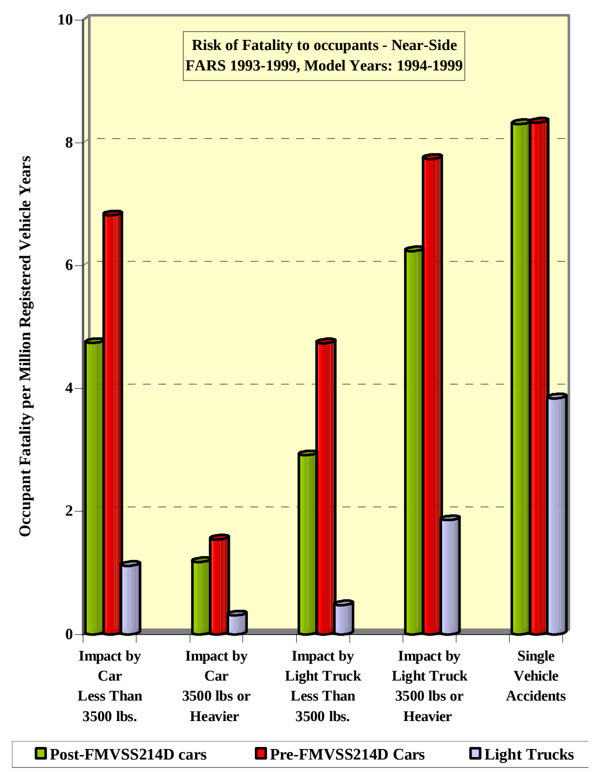

Figure 16: Occupant fatality rates for Pre-FMVSS 214D vs Post-FMVSS 214D passenger cars.

A likely reason for this is that the FMVSS 214 test procedure and test barrier (a moving deformable barrier) are realistic representations of the current US fleet and therefore, vehicles designed to comply with this regulation show improved safety performance. As a comparison[7], vehicles designed to improve the frontal NCAP score have not shown any correlated improvement in overall safety since the test procedure and test barrier may not represent real world conditions.

CONCLUSIONS

The issue of collision compatibility between larger vehicles and smaller passenger cars has many aspects and it is necessary to understand them in order to find solutions that improve 'partner protection' without degrading 'self protection'. The data presented above show that the side impact mode between LTVs and passenger cars is the most frequent mode and accounts for more occupant harm than the front impact mode. Almost all of the harm in the side impact mode is due to impacts on the passenger compartments whose direction lies between 10 o'clock and 2 o'clock. For frontal impacts between LTVs and cars, the single largest subcategory is full frontal crashes. This information can be used to set priorities for improving crash compatibility between vehicles.

The observation to be made from the correlation between dynamic FMVSS 214 compliance and injury reduction is that crashworthiness test procedures need to realistically represent the existing, real-world conditions on the road if meaningful gains in safety are to be made. Since the existing safety criteria - regulations and consumer metrics - were established primarily with the aim of improving self protection, it is important that these be re-evaluated with the changing composition of the vehicle fleet and appropriate changes be made to reduce the total number of injuries and fatalities. This re-evaluation needs to account for the inherent properties that the test barriers have and their effect on a vehicle's structural design.

It is also to be observed from the data presented above that significant gains in crash compatibility have been obtained by improving the performance of the struck vehicle in side impact, such as by required compliance with the FMVSS 214. It is therefore appropriate that future efforts to improve crash compatibility also consider potential solutions and performance requirements for the struck (or the smaller 'partner') vehicle that may have near-term potential.

ACKNOWLEDGEMENT

We are thankful to Dr Karuna Ramachandran of Exponent Failure Analysis Associates for providing some of the data and the analysis used in this paper.

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